Bioregional planning in central Georgia, USA

Virginia Dale[a,*], Matthew Aldridge[b], Taryn Arthur[a],
Latha Baskaran[a], Michael Berry[b], Michael Chang[c],
Rebecca Efroymson[a], Chuck Garten[a], Catherine Stewart[d],
Robert Washington-Allen[e]

[a]*Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008,
1 Bethel Valley Road, Oak Ridge, TN 37831-6036, USA*
[b]*Department of Computer Science, University of Tennessee, Knoxville, TN 37996, USA*
[c]*School of Atmospheric & Earth Sciences, Georgia Institute of Technology, Atlanta, GA 30332, USA*
[d]*US Army Center for Health Promotion and Preventive Medicine, Environmental Noise Program,
Aberdeen Proving Ground, MD 21010, USA*
[e]*Department of Forest, Range, and Wildlife Sciences, Intermountain Region Digital Image Archive Center,
Utah State University, Logan, UT 84321-5230, USA*

Available online 2 November 2005

Abstract

Human influences in the five-county region around Fort Benning, Georgia, USA, have been long and intense. Only 4% of the native longleaf pine (*Pinus palustris*) forest remains intact. Besides the loss of species, habitats, and ecosystem services associated with longleaf pine forests, the environmental concerns of the region include air, water, and noise pollution. The mix of federal and private ownership in this region leads to complicated land-management issues that will likely become even more difficult as the city of Columbus continues its projected growth along the northern border of Fort Benning. To understand how anthropogenic developments affect the environment, we are developing a Regional Simulator (RSim) to project future developments and their impacts on environmental conditions. Using RSim, we can identify the potential effects of growth on noise and air pollution, water-borne nutrients, and habitats for focal species. Noise impacts are already large in the areas of current and projected urban growth for the region. This knowledge of potential futures allows options for environmental protection to be considered. A key lesson from this analysis is that regional simulation models are a cost-effective way to assess the long-term environmental implications of anthropogenic growth and development. Published by Elsevier Ltd.

---

* Corresponding author. Tel.: +1 865 576 8043; fax: +1 865 576 8543.
E-mail address: dalevh@ornl.gov (V. Dale).

Report Documentation Page

1. REPORT DATE **02 NOV 2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**

4. TITLE AND SUBTITLE **Bioregional Planning in Central Georgia, USA**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Environmental Sciences Division,Oak Ridge National Laboratory,P.O. Box 2008, 1 Bethel Valley Road,Oak RIdge,TN,37831-6036**	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**19**	

1. Description of five-county study region

The region for this study is the five-county area around Fort Benning, Georgia, in the southeastern United States (Fig. 1). These counties occur along the fall line that bisects Fort Benning and differentiates between the coastal plain and the Piedmont. The fall line occurs where the Piedmont transitions into the Southeastern Plains (following the ecoregion definitions set forth by Omernik) [40,41]. This area is characterized by strong gradients in topography and soils ranging from rolling sandy–clay hills to sandy plains. The fall line extends from central Alabama northeasterly to North Carolina and was once dominated by longleaf pine (*Pinus palustris*), but only 4% of the original longleaf pine forest remains [47]. Loss of the longleaf pine forests is primarily due to land-use change, timber harvesting, and fire suppression [28,30]. Longleaf pine is a fire-adapted species; small trees can withstand the light, frequent fires typical of these systems. Fires can also reduce growth of hardwood trees into the overstory. The longleaf pine is considered a keystone species, for it supports many other organisms, including the federally endangered red-cockaded woodpecker (*Picoides borealis*). The woodpeckers are unique in that they create cavities in living trees that provide homes for at least 23 other species [12]. Hence, protection of and habitat management for the red-cockaded woodpecker and longleaf pine forest is a top priority for federal land managers. Although an understanding of the effects of human modifications and alterations on longleaf pine systems is developing [22,34, 42,43], much still remains to be learned about how human impacts on the longleaf pine system will affect future forest conditions.

About 75% of the current longleaf forest is in private ownership and caters to a variety of services, including recreation and timber extraction. The remaining forest occurs on public land. Large patches of intact longleaf pine forest best represent typical ecological conditions and hence support the highest number of native species [38]. Most of the larger patches of longleaf pine forest are in federal ownership, managed primarily by the Department of Defense (DoD) or the Forest Service [58]. An effective form of habitat management of longleaf pine forest is prescribed ground fires about every 3 years, which kill hardwoods and other conifer species.
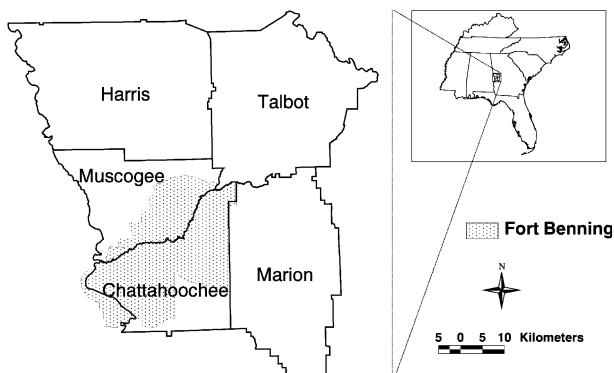

Fig. 1. The five-county study area around Fort Benning, Ga, shown in relation to the southeastern United States.

Fort Benning has been the 'home of the infantry' since 1918, when the land was first acquired for military use, and it is now the site of much infantry- and tank-training activity. Before that time, European settlers practiced intensive agriculture on the land beginning in the 1800s, and earlier still, Native Americans occupied settlements along the rivers and hunted and grew crops for centuries [31]. The Fort Benning Army Installation occupies 73,503 ha in Chattahoochee, Muscogee, and Marion counties of Georgia and Russell County of Alabama. Military training occurs on much of the installation, although there are also large areas of relatively untouched forests. In 1827, pine forests occupied about 75% of the area that became Fort Benning [11]. By 1974, only 25% of the installation was in pine, though this area had gradually increased to 35% by 1999 under management activities designed to facilitate pine establishment (e.g. regularly prescribed fires and planting longleaf pine) [10]. Probably, because much of the installation was protected from land development, it now supports ecosystems and species that were once common in the southeastern United States but are now quite rare (such as occurs on lands managed by the Department of Energy [33]).

The lands in the five-county region outside Fort Benning are largely under private ownership and have a mix of land-cover types. The city of Columbus, GA, is directly to the north of Fort Benning, and its growth has already constrained some activities on the installation. The rest of the five-county region is a mix of urban, bare-ground, nonforested vegetation (largely agriculture), and forested land (Fig. 2). Over the past 30 years, the human population of Chattahoochee County has declined, and that of Talbot County has remained constant, but the populations of the other counties have increased [48]. The study region lies between Atlanta, one of the fastest-growing cities in the United States, and Florida, one of the fastest-growing states [56], and as their populations increase, so will their influence on the study region.

The climate of the region is humid and mild, with rainfall occurring regularly throughout the year. Average annual precipitation is 105 cm, with October being the driest month. The warmest months are July and August, which have daily maximum and minimum temperatures averaging 37 and 15 °C, respectively. The coldest months, January and February, have average daily maximum and minimum temperatures of 15.5 and −1 °C, respectively.

2. Current planning efforts

With stakeholders including several different levels of government (federal, state, five counties, several cities, and the Columbus-Muscogee consolidated government), the Army at Fort Benning, countless nonprofit advocacy groups, private landowners, and many others, current land-use planning efforts in the region reflect complex and frequently competing demands for economic development, environmental conservation, and military expedience. Nevertheless, as the current array of land-management efforts demonstrates, there are wide windows of opportunity for cooperation, largely because even those stakeholders who are not interested in conservation as a primary goal have incentives for pursuing sustainable development. Furthermore, most planning efforts focus on
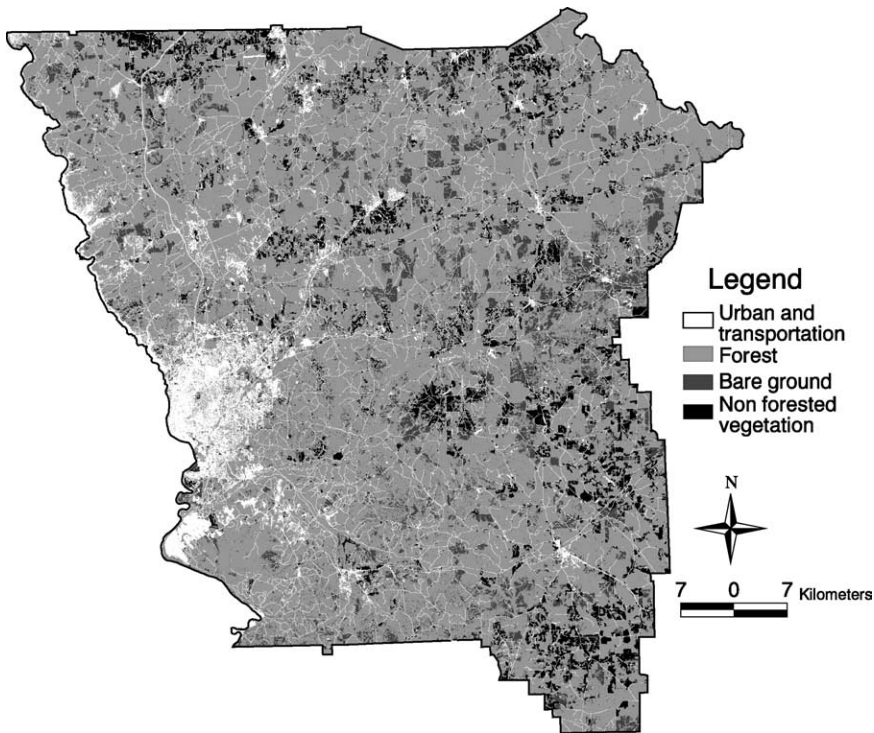
Fig. 2. Land cover uses in 1998 in the five-county region.

the decadal time scale or less; yet changes over a longer period of time also need to be considered.

2.1. Economic planning

In general, future economic development in the area will lead to a push to further develop land in the area. Both the state and local governments in the study area have taken steps to attract businesses over the next 15 years. The state of Georgia encourages new and expanding businesses by offering a variety of tax and other incentives, including a permit process that does not require a formal environmental impact statement [23]. The five counties in the study—Chattahoochee, Harris, Marion, Muscogee, and Talbot—have joined with Taylor County and the cities of Manchester in Meriwether County and West Point in Troup County to form the Valley Partnership Joint Development Authority to combine their resources and incentives [54]. Economic development without tighter controls on real estate planning, however, could add to future land-management conflicts by contributing to the sprawl for which Georgia's metropolitan areas have already become notorious.

Economic development has received further state support in the form of the Georgia Department of Transportation's (DOT) Governor's Road Improvement Program (GRIP).

GRIP aims to improve transportation infrastructure over a 10-year period in order to foster economic growth, particularly in rural areas, by widening existing interstates, highways, and state roads [3]. Within the five counties of this study, one interstate, (I-185), and three US highways (27, 80, and 280) were earmarked for improvement under GRIP. As of January 2004, all work had been completed except for the stretch of US 27 south of the junction with US 280 in Chattahoochee County and a stretch of US 80 located in eastern Talbot County [25]. Increased transportation infrastructure will logically lead to increased urbanization, as development springs up alongside roadways.

Economic development and ecological conservation are not necessarily wholly incompatible, however. Current landowners tend to find that the presence of green space increases the value of their property, and thus they often have an incentive to block further development, or at least to concentrate it within a smaller area. For example, in Fulton County, to the northeast of this study's region, landowners have established the Chattahoochee Hill Country Alliance, which won approval from the County Commission for a 10-year plan to establish a 'model village' with large areas of green on their property [62]. Moreover, economic growth does not necessarily have to equal sprawl. Atlanta is currently experimenting with 'smart growth' development [45], which builds high-density commercial and residential complexes, often centered on transit systems. Zoning codes and public ambivalence about the smart growth concept currently hamper the effort [21], but future success in Atlanta could provide a model for the region.

2.2. Environmental planning

Ecological conservation programs that affect the five-county region of this study have been undertaken by a wide variety of public and private actors, frequently operating in cooperation with one another. A collaboration of the Environmental Protection Agency (EPA) Region 4 and the University of Florida produced the Southeastern Ecological Framework (SEF) [5], which acts as a guidebook for many land-use planning programs throughout an eight-state region (Florida, Georgia, South Carolina, North Carolina, Alabama, Mississippi, Tennessee, and Kentucky). The SEF used a GIS model to identify a network of ecologically significant 'hubs' and the 'corridors' connecting them. The EPA has used the study to prioritize programs in its own decision making and has made the data and results available to federal, state, and local government agencies, as well as to nonprofit organizations [5]. In addition to the static SEF, other publicly available EPA initiatives designed to help communities comply with federal environmental standards include the Economic Growth Analysis System (EGAS). EGAS uses a model to predict growth and the corresponding emissions over 25 years, to help communities satisfy their obligations under the Clean Air Act and the National Ambient Air Quality Standards [18].

Between 1990 and 2000, Georgia was the sixth fastest-growing state in the country, according to the US Census [56]. In an effort to restrain development, in 2000 the state implemented the Georgia Community Greenspace Program. The program provided funding for land acquisition to counties with a population of at least 60,000 or an average annual growth rate of 800 people. Eligible counties could receive funds by submitting a plan to preserve at least 20% of their land as greenspace. Of the five counties in this study, only Muscogee received program funding—a total of over $1.12M in FY 2001–2002 [24].

The Greenspace Program was discontinued in 2003 when funding was cut by incoming governor Sonny Perdue. As a replacement, the governor has proposed the Georgia Land Conservation Partnership, which would redistribute the financial burden of acquiring land for greenspace, either by issuing bonds or soliciting funds from local governments, nonprofit organizations, and individual philanthropists [50].

One model for a broad-participation approach is the Chattahoochee River Land Protection Campaign, which has brought together a broad coalition of governmental and nongovernmental actors, spearheaded by the Trust for Public Land, The Nature Conservancy, and the Georgia Conservancy. The coalition aims to create a buffer zone along a 290-km stretch of the Chattahoochee River, from the mountains of North Georgia to the city of Columbus. Through a combination of acquisitions, donations, and easements, as of November 2003 the initiative had managed to protect 4046 ha of land along 100 km of the river [44,53].

The quality of the water in the Chattahoochee has been subject to much scrutiny over the past few years, as an EPA project to assess water pollution shifted its attention to the Chattahoochee River Basin in 2002. A handful of water bodies in the study region were found to be contaminated, in most cases with the pathogen fecal coliform and/or polychlorinated biphenyl chemical compounds. The state of Georgia has therefore been obligated under the Clean Water Act to issue total maximum daily loads (TMDLs) for these pollutants [26]. According to the EPA definition, a TMDL assesses the maximum amount of a pollutant that a water body can receive and yet still comply with water quality standards, and then divides that amount among the pollutant's sources [57]. This information is relevant to many players on the middle Chattahoochee watershed, including Columbus Water Works (CWW), which has been responsible for providing drinking water and collecting wastewater for the Greater Columbus region since 1902. CWW has made national news with its innovative initiatives, most recently for implementing a program to use municipal waste as fertilizer [36]. Currently, CWW is working on a plan to establish a permanent monitoring and data-management system, and ongoing projects are carried out with the cooperation of a number of stakeholders, including Georgia Institute of Technology, the Georgia Conservancy, and other nonprofit organizations [8].

The future of water quantity in the region will be affected by the results of ongoing water-rights litigation. Georgia, Alabama, and Florida spent 5 years trying to negotiate an agreement on use of water from the Apalachicola–Chattahoochee–Flint river system. The process culminated in a tentative agreement in July 2003, but a few months later Florida refused to accept the terms, preferring to appeal to the Supreme Court. The final agreement will probably take years to settle, but it seems certain that water shortages will have profound environmental and economic impacts, with possibilities ranging from restricted irrigation, higher rates, and stricter dumping laws, since there is less water to dilute any pollution [49].

Longleaf pine, a prominent species at Fort Benning, has also attracted conservationists' attention. The Longleaf Alliance, based at the Solon Dixon Forestry Education Center and Auburn University's School of Forestry and Wildlife Services, works with conservationists and land managers to increase awareness and provide guidance on maintaining and restoring longleaf forests, particularly on privately held lands [32].

Often, conservation is practiced by private landowners who agree to establish easements on their land. Agreements on the duration and the conditions of the easement are negotiated on a case-by-case basis, and the holder of the easement can be either a government entity—frequently city and county governments, the Georgia Department of Natural Resources, or the US Fish and Wildlife Service—or a private, nonprofit land trust [2]. The Department of Agriculture's Natural Resources Conservation Service (NRCS) also sponsors several initiatives in Georgia. NRCS offers financial and technical assistance in a number of areas to landowners who are willing to practice conservation on their property, e.g. by establishing an easement and/or restoring a wetland [37].

2.3. Military planning

Conservation advocates frequently find an ally in the military through a combination of mutual interests and the military's obligations as a publicly supported institution. The Sikes Act of 1960 laid the groundwork for cooperation among government agencies for environmental conservation on military property. Over the following decades, the law was modified multiple times [51], and was joined by legislation, such as the Endangered Species Act, the Clean Air Act, the Safe Drinking Water Act, and other acts that were binding on the military as well as on the general population. To cope with its increasing environmental obligations, in 1989 DoD issued a directive for all DoD land managers to establish a natural resources management program [14], and in 1997 amendments to the Sikes Act, Congress mandated such programs. In the late 1990s, the Army's response to these obligations coalesced into two separate but closely related programs for land management at its installations: the Integrated Training Area Management (ITAM) program and the Integrated Natural Resources Management Plan (INRMP). The Integrated Training Area Management program is made up of four subprograms: (1) Land Condition Trend Analysis (LCTA), which is responsible for managing environmental data, primarily in the form of GIS mapping; (2) Training Requirements Integration (TRI), which is responsible for synthesizing training demands with natural resource preservation; (3) Land Rehabilitation and Maintenance (LRAM), which is responsible for preventing damage to training areas and repairing damage that is incurred; and (4) Environmental Awareness (EA), which is responsible for public relations and education [13]. The program has met with both success [35] and skepticism—the latter primarily focused on the Land Condition Trend Analysis component of the program. For example, Prosser and others [46] noted that the LCTA technique was developed in the ecosystems of Colorado and Texas and that, consequently, a base in a different ecosystem should consider sampling methods that are potentially more relevant. They further added that collecting LCTA data is labor-intensive and time-consuming [46].

One of the duties of the Training Requirements Integration component of ITAM is to provide input for an Integrated Natural Resources Management Plan. Each installation's INRMP outlines its goals for integrating military needs with effective management of natural resources and indicates how those objectives will be achieved. The responsibility for preparing and implementing the INRMP falls on the installation commander, who in turn solicits input from other government agencies, scientific experts, conservation groups,

neighboring landowners, and others with a stake in the environmental future of the installation. The plans must be kept current and reapproved every 5 years [15].

The INRMP for Fort Benning, the installation in this study, was prepared with the help from The Nature Conservancy (TNC). The plan contains a list of 21 goals, which are to be accomplished by means of 150 tasks, ranging from prescribed burns for the promotion of longleaf pines to measures to encourage the proliferation of the red-cockaded woodpecker [29]. The latter task is rendered more difficult by the uncertainty surrounding the degree of impact that military training has on the woodpecker. TNC researchers were unable to establish that nearby firing ranges had an impact on the birds' reproductive behavior. Nevertheless, they advise avoiding any changes in the current scale and areas of range training [17].

In addition to its conservation duties, however, Fort Benning has an obligation to train soldiers. For this purpose, Fort Benning currently is constructing a new digital multipurpose range complex (DMPRC). The proposed DMPRC would cover approximately 730 ha and would provide facilities for training with the Bradley Fighting Vehicle and the Abrams M1A1 tank. The project's environmental impact statement predicts that construction will negatively impact air and water quality in the short-term as a result of the clearing of trees and removal of soil and that the project will have a long-term negative impact on wetlands and federally protected species, including the red-cockaded woodpecker. The findings of the Final Environmental Impact Statement (FEIS) suggest that the No Action alternative (i.e. no construction) has the fewest potential impacts; however, noise concerns would continue, and needed improvement in range facilities would not occur [16]. Alternatives II and III in the EIS would have negative effects on several resources; however, mitigations are identified in the FEIS that would reduce those impacts, and both alternatives would result in less noise disturbance from the Bradley fighting vehicle and tank weaponry firing than currently occurs. Fort Benning has asked the Strategic Environmental Research and Development Program (SERDP) Ecosystems Management Project, of which our research team is a part, to analyze the issue further [59].

A major issue where military and conservation stances coincide is that of encroachment onto undeveloped areas around installations. From the military's perspective, the primary concerns are twofold: (1) a reduction in natural habitat outside the base will put pressure on military personnel to step even more delicately with regard to the environment on the base, since a decrease in natural habitat could drive endangered species onto the base's property or could make the populations on the installation be even more rare; (2) the proximity of civilians to the borders of the installation will lead to problems ranging from noise complaints to electromagnetic interference [19]. Noise ordinances are set locally, and although they are not applicable to installation property itself, they can become an issue when the sound emanates into the surrounding community. Therefore, military bases prefer to acquire buffer zones around their property, which can be accomplished by acquiring land, coming to an agreement with neighboring landowners, or, on occasion, condemning the land. Some bases have entered into cooperative, cost-sharing agreements with advocacy groups in order to gain possession of land on their borders. For example, through DoD's Private Lands Initiative, TNC is jointly purchasing off-post land with Fort Bragg in North Carolina [61], and TNC and the Trust for Public Land's Greenprint Program are working to help buffer Fort Stewart, Georgia [52]. Fort Benning could elect to

do the same in a future project. Meanwhile, our research team and others are working to determine the scope of the future encroachment problem (as described later in this paper).

State and local authorities are also striving to address the encroachment problem, largely as a result of the jolt they have received from DoD in the form of the Base Realignment and Closure (BRAC) program. Under BRAC, DoD is currently evaluating the missions of all military installations to determine where cuts and reshuffling can be carried out [39], and encroachment will likely be a factor in the decisions on which bases will be closed in 2005. In an effort to protect Georgia's numerous military facilities and the benefits that they bring to local economies, in June 2003 Governor Perdue signed into law a bill that requires local governments to consult with military bases on zoning decisions for land within 3000 ft of the base [9]. Fort Benning itself is unlikely to be closed; in fact, Columbus city officials have seized on the opportunity to try to expand Fort Benning by acquiring for their local base some of the missions currently carried out by bases slated for closure, even hiring a consulting firm to help strategize [60]. In short, local authorities are currently primed to be very receptive to Fort Benning's land-use preferences in the buffer zone around the installation.

3. Treatment of the future

The need for applying ecosystem management approaches to military lands and the regions that contain them is critical because of unique resources on these lands and the fact that inappropriate management of conservation issues may jeopardize military missions. We are building a computer simulation model, the Regional Simulator (RSim), to integrate land-cover changes with effects on noise, water and air quality, and species of special concern and their habitats. The RSim model is being developed for the region around Fort Benning because of the large amount of data available for the installation and surrounding region and the cooperation offered by the base in developing and testing the model. However, this spatially explicit model is being designed so that its basic framework can be applied to other military installations and their regions, thus ensuring broad applicability to DoD environmental management concerns.

Numerous future scenarios can be modeled using RSim. These include both civilian and military land-cover changes. We have modeled two specific scenarios, along with their impacts on environmental conditions over the next 300 years: (1) modeled urbanization (conversion of nonurban land cover to low-intensity urban and conversion of low-intensity to high-intensity urban), and (2) planned road expansion plus modeled urbanization. One intended use of RSim is to create scenarios of new developments resulting from changes in policy for federal, state, or private lands in order to explore their environmental impacts. For example, management policy for the longleaf pine forest may be revised when the Fish and Wildlife Service updates its recovery plan for the federally threatened species that inhabits these forests (red-cockaded woodpecker). Closure of some military installations and ongoing military engagement around the world will put pressure on Fort Benning to train more infantry troops. RSim should allow the environmental implications of these changing conditions to be explored.

3.1. Modeling urbanization

Our methods for simulating population growth generated new urban pixels in land-cover maps for the five-county region around Fort Benning. Urban growth rules are applied at each iteration of RSim to create new urban land cover. The subsequent RSim modeling step then operates off a new map of land cover for the five-county region. The computer code (written in Java) has been built from the spontaneous, spread center, and edge growth rules of the urban-growth model from Sleuth [4,6,7,27].

The urban-growth submodel in RSim includes both spontaneous growth of new urban areas and patch growth (growth of preexisting urban patches). We have focused first on generating low-intensity urban areas (e.g. single-family residential areas, schools, city parks, cemeteries, playing fields, and campus-like institutions). Three sources of growth of low-intensity urban pixels are modeled: spontaneous growth, new spreading center growth, and edge growth. First, an exclusion layer is referenced to determine those pixels not suitable for urbanization. The exclusion layer includes transportation routes, open water, the Fort Benning base itself, state parks, and a large private recreational resort (Callaway Gardens). Spontaneous growth is initiated by the selection of *n* pixels at random, where *n* is a predetermined coefficient. These cells will be urbanized if they do not fall within any areas defined by the exclusion layer. New spreading-center growth occurs by selecting a random number of the pixels chosen by spontaneous growth and urbanizing any two neighboring pixels. Edge-growth pixels arise from a random number of nonurban pixels with at least three urbanized neighboring pixels.

Low-intensity urban pixels become high-intensity urban cells according to different rules for two types of desired high-intensity urban cells:

- central business districts, commercial facilities, high impervious surface areas (e.g. parking lots) of institutional facilities that are created within existing areas with a concentration of low-intensity urban cells;
- industrial facilities and commercial facilities (malls) that are created at the edge of the existing clumped areas of mostly low-intensity urban cells or along four-lane roads.

For the first high-intensity category, land-cover changes occur in a manner similar to changes in low-intensity growth, as described above: a spontaneous-growth algorithm converts random low-intensity pixels to high-intensity pixels, and an edge-growth algorithm converts random low-intensity urban pixels with high-intensity urban neighbors to high-intensity pixels. The second type of conversion, from low-intensity to high-intensity urban land use, is road-influenced growth and is described in Section 3.2.

3.2. Modeling the effects of roads on urban growth

The road-influenced urbanization submodel of RSim consists of growth in areas near existing and new roads by considering the proximity of major roads to newly urbanized areas. The new-road scenario makes use of the Governor's Road Improvement Program

(GRIP) data layers (as described above) for new roads in the region. Upon each iteration (time step) of RSim, some number of nonurban pixels in a land-use land-cover map are tested for suitability for urbanization according to spontaneous and patch growth constraints. For each pixel that is converted to urban land cover, an additional test is performed to determine whether a primary road is within a predefined distance from the newly urbanized pixel. This step is accomplished by searching successive concentric rings around the urbanized pixel until either a primary road pixel is found or the coefficient for a road search distance is exceeded. If a road is not encountered, the attempt is aborted.

Assuming the search produces a candidate road, a search is performed to seek out other potential pixels for urbanization. Beginning from the candidate road pixel, the search algorithm attempts to move a 'walker' along the road in a randomly selected direction. If the chosen direction does not lead to another road pixel, the algorithm continues searching around the current pixel until another road pixel is found, aborting upon failure. Once a suitable direction has been chosen, the walker is advanced one pixel, and the direction selection process is repeated.

In an effort to reduce the possibility of producing a road trip that doubles back in the opposite direction, the algorithm attempts at each step of the trip to continue moving the walker in the same direction in which it arrived. In the event that such a direction leads to a nonroad pixel, the algorithm's search pattern fans out clockwise and counterclockwise until a suitable direction has been found, aborting upon failure. Additionally, a list of road pixels already visited on the current trip is maintained, and the walker is not allowed to revisit these pixels.

The road-trip process continues until it must be aborted due to the lack of a suitable direction or the distance traveled exceeds a predefined travel limit coefficient. The latter case is considered a successful road trip. To simulate the different costs of traveling along smaller two-lane roads and larger four-lane roads, each single-pixel advancement on a two-lane road contributes more toward the travel limit, allowing for longer trips to be taken along four-lane roads such as the GRIP highways.

Upon the successful completion of a road trip, the algorithm tests the immediate neighbors of the final road pixel visited for potential urbanization. If a nonurban candidate pixel for urbanization is found, it is changed to a low-intensity urban type, and its immediate neighbors are also tested to find two more urban candidates. If successful, this process will create a new urban center that may result in spreading growth as determined by the edge-growth constraint.

As noted in Section 3.1, roads also influence the conversion of low-intensity urban land cover to high-intensity urban land cover. For the second high-intensity urban subcategory (industry and malls), the RSim code selects new potential high-intensity-urbanized cells with a probability defined by a breed coefficient for each cell. Then, if a four-lane or wider road is found within a given maximal radius (5 km, which determines the road_gravity_coefficient) of the selected cell, the cells adjacent to the discovered four-lane or wider road cell are examined. If suitable, one adjacent cell is chosen for high-intensity urbanization. Hence, the new industry or mall can be located on the highway, within 5 km of an already high-intensity urbanized pixel.

3.3. Modeling noise impacts

Noise from military installations may affect populations outside of base boundaries and wildlife within the fence. RSim uses GIS data layers of military noise exposure developed by the US Army Center for Health Promotion and Preventive Medicine (CHPPM) as part of the Fort Benning Installation Environmental Noise Management Plan (IENMP). RSim builds upon noise guideline levels developed by the military under the Army's Environmental Noise Program [ENP] [55]. ENP guidelines define zones of high noise and accident potential and recommend uses compatible in these zones. Local planning agencies are encouraged to adopt these guidelines. IENMP contains noise contour maps developed from three DoD noise simulation models: NOISEMAP, BNOISE, and SARNAM.

- The Army, Navy, and Air Force use NOISEMAP (Version 6.5), a widely accepted model that projects noise impacts around military airfields. NOISEMAP calculates contours resulting from aircraft operations using such variables as power settings, aircraft model and type, maximum sound levels and durations, and flight profiles for a given airfield.
- The Army and the Marines use BNOISE to project noise impacts around ranges where 20-mm or larger caliber weapons are fired. BNOISE takes into account both the
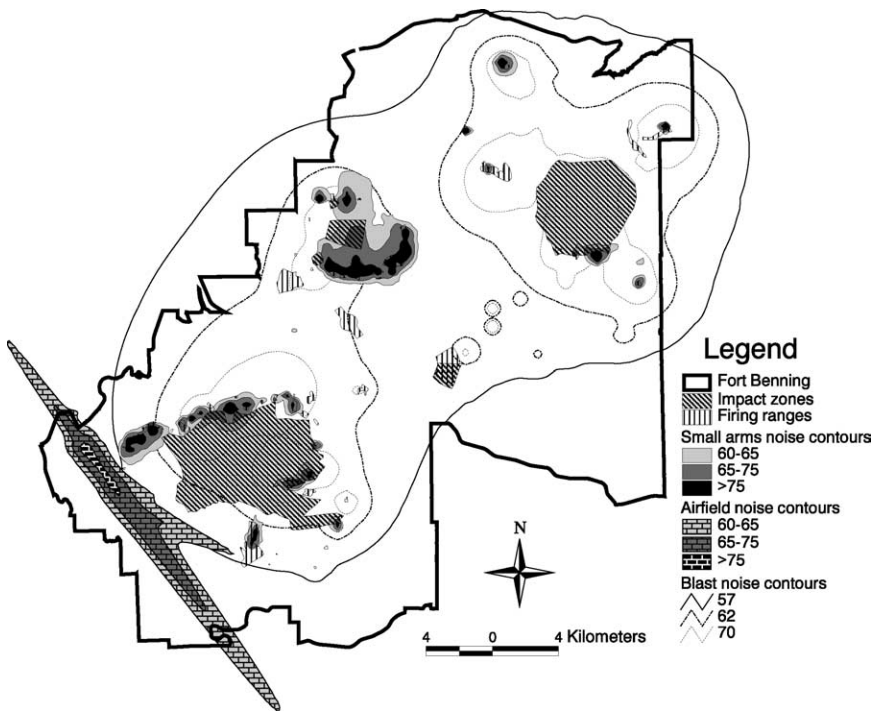

Fig. 3. Noise impact contours (in decibels) for the Fort Benning area.

annoyances caused by hearing the impulsive noise of weapons and by experiencing house vibration caused by the low frequency sound of large explosions. BNOISE uses operational data on the number of rounds of each type fired from each weapon broken down by day and night firing. Contours show the cumulative noise exposure from both firing point and target noise.

- All the military services use the Small Arms Range Noise Assessment Model (SARNAM) to project noise impacts around small arms ranges. SARNAM is designed to account for noise attenuated by different combinations of berms, baffles, and range structures.

Each model produces noise contours that identify areas where noise levels are compatible or incompatible with noise-sensitive land covers. The output could also be used to determine the effects of noise on wildlife if species audiograms and spectra for noise sources are available. The common output of all three noise models (Fig. 3) allows RSim projections to be overlain on the GIS data layer from the noise models.

4. Assessment of the future of the five-county region

RSim projections of urban growth show that the city of Columbus is expected to grow and hence to exert even more pressure on the northern boundary of Fort Benning (Fig. 4). With no zoning or other restrictions, the model projects that both low-intensity and high-intensity urban land covers will occur along the northern boundary of the installation. Urban growth in Harris County (farther north of Fort Benning) is also expected to be high. This growth is likely to come from preexisting communities, but such development would
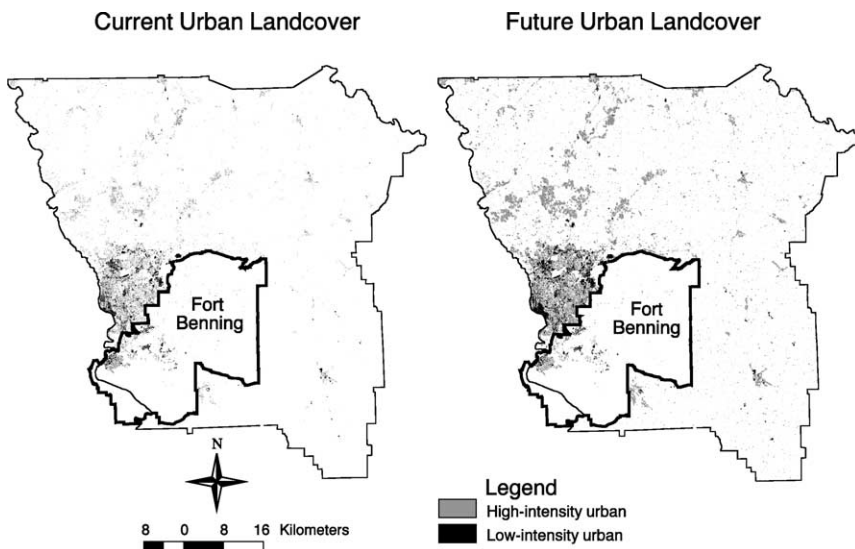

Fig. 4. Current and projected urban land cover for five-county region.

Table 1
Land cover for the study region in 1998 and projected with and without new roads

Class	Area (ha)			% Cover		
	1998	Projected with new roads	Projected without new roads	1998	Projected with new roads	Projected without new roads
Urban and transportation	41,874	60,354	59,636	9	14	14
Bare ground	45,532	43,125	43,222	10	10	10
Forest	311,424	297,522	298,048	72	68	68
Nonforest vegetation	36,550	34,381	34,475	8	8	8
All classes	435,380	435,383	435,382	100	100	100

also make sense in view of the proximity of Atlanta, which grew by 38.9% between 1990 and 2000 and continues to grow at a rapid rate [56]. Harris County is within commuting distance for people working in Atlanta. Over the five-county region the RSim model projects a small increase in urban areas with most of the land cover coming from forested areas (Table 1).

With the expansion of roads, RSim predicts very little change in urban growth compared to the projection without the influence of new roads (Table 1). With new roads included in the model, less than 0.2% more area is converted to urban sites as a direct result of the roads [10]. Hence, new roads are not anticipated to have many new direct impacts on land-cover change in this region, in contrast to the great effect of new roads in rural areas of developing countries [20]. In the United States, few new roads are being created, and most environmental effects arise from existing or renovated roads [20].

We are most interested in using the RSim model to project ways in which land-cover changes will have direct and indirect impacts on noise, water, and air quality and rare species. Here, we focus on the effects of noise. By overlaying the noise contours from military activities on current and projected urban growth, we can determine what land-cover classes are or will be exposed to high noise levels. Projections from the noise models for Fort Benning show that noise levels are high in areas to the northwest of the installation, where urban growth is projected to occur, and to the east, where a mix of forested and nonforested lands occurs (Fig. 2). The noise levels are reported according to C-weighting [1], which are impulsive sounds such as sonic booms and are perceived by more than just the ear. These vibrations are flat over the range of human hearing (about 20–20,000 Hz). Quantities of interest for human annoyance include: (1) the C-weighted day-night sound levels (CDNL) between 62 and 70 dB, termed 'Noise Zone II', in which the location of residences is not recommended and (2) CDNLs between 57 and 62 dB, termed the 'Land Use Planning Zone', in which noise complaints may arise. Urban areas with sound levels of 57–62-dB CDNL (Table 2) and 62–70-dB CDNL (Table 3) are potentially affected by noise both now and in the future, in particular in areas where noise reduction features have not been incorporated into buildings (Tables 2 and 3). Both with and without the new road scenario, about 20% of the land in the 57–62-dB CDNL contour is projected to be in urban cover. The mission at Fort Benning would be protected if urban

Table 2
Land cover between the 57- and 62- dB noise contours in 1998 and projected with and without new roads

Class	Area (ha)			Percentage		
	1998	Projected with new roads	Projected without new roads	1998	Projected with new roads	Projected without new roads
Urban and transportation	5253	6594	6603	16	20	20
Bare ground	2720	2448	2448	8	7	7
Forest	23,615	22,680	22,678	72	69	69
Nonforest vegetation	1300	1166	1160	4	4	4
Total	32,888	32,888	32,888	100	100	100

land use could be discouraged in that area. Thus, this modeling example is being used to alert local planners of this impending conflict. We are building subcomponents for RSim to examine air and water quality and habitat effects in a similar manner.

5. Concluding thoughts

Planners in the five-county region of Georgia are extremely interested in future developments of the state, counties and municipalities. Their efforts focus on meeting economic needs and providing clean water and air over the next 5–20 years. The military planners are most concerned with addressing training requirements while obeying environmental laws and regulations and maintaining good relations with their neighbors. Fort Benning tends to be assigned a new garrison commander about every 5 years. Hence the installation tends to focus on the 5-year time scale or less, for it is within the planning budgets and community experience. Yet, some environmental repercussions of land management practices may not be apparent for several decades. Therefore, bioregional planning should include the long term.

Table 3
Land cover between the 62- and 70-dB noise contours and projected with and without new roads

Class	Area (ha)			Percentage		
	1998	Projected with new roads	Projected without new roads	1998	Projected with new roads	Projected without new roads
Urban and transportation	2181	2207	2208	11	11	11
Bare ground	1451	1448	1445	7	7	7
Forest	14,598	14,582	14,584	74	74	74
Nonforest vegetation	1483	1476	1476	8	8	8
All classes	19,713	19,713	19,713	100	100	100

The RSim model offers several benefits to the research community and resource managers. The model design and building effort is intended to contribute to workable management and monitoring plans. RSim is being designed so that it can be incorporated into existing management systems for an installation and also to relate to the needs of private resource managers and developers for the area. RSim provides a tool for planners to consider environmental impacts up to and beyond the 5-year time frame, which is the typical focal period. The model provides new ways to consider the influence of different spatial scales and types of feedback and to minimize environmental impacts. We are developing an approach that integrates processes that operate on very different temporal and spatial scales. For example, the air-quality model is an instantaneous projection for a large area, while the water-quality model operates seasonally and has spatial units of 30-m resolution. The plan is to have RSim incorporate feedback between different aspects of the environment that operate at different spatial scales and to focus on projections over a decade or more. Accommodating such feedback relationships is one of the biggest challenges of interdisciplinary research.

There is a need for an integrated perspective in addressing environmental concerns. Current environmental laws and regulations address such concerns by sector but may impact other sectors and often occur without consideration for how solving one problem may create another (e.g. actions designed to meet local noise standards may jeopardize water or air quality). There are few attempts to design approaches that allow resource managers to consider ways in which environmental management or restoration affect the variety of environmental concerns. RSim is designed to be such a tool. Hence, the model should improve the ability to manage for multiple concerns. Such an integrative approach may lead to steps to simultaneously and proactively address environmental laws and regulations. Optimization is a key issue for environmental research, as advancements have been constrained by efforts to meet a single criterion. Acceptable land covers are those that maintain standards within all environmental categories—air and water quality, noise control, and species protection.

Maybe the greatest contribution and challenge of this approach is in its long-term and regional perspective. Historically, many environmental efforts have focused on addressing impacts over a few years and within a single land ownership or within similar land uses. Using RSim, we examine long-term impacts within a region that includes many different owners and land uses.

Acknowledgements

References

[1] ANSI, Quantities and Procedures for Description and Measurement of Environmental Sounds, Part 1, 1988 (American National Standards Institutre Standard ANSI S12.9-1988).

[2] A Landowner's Guide: Conservation Easements for Natural Resource Protection: http://www.gepinstitute.com/consease.htm.

[3] D.C. Bachtel, M. Ragsdale, K.E. Dowd, An Analysis of the Governor's Road Improvement Program (GRIP) for the Georgia Department of Transportation.

[4] J.C. Candau, Temporal calibration sensitivity of the SLEUTH urban growth model, MA Thesis, University of California, Santa Barbara, 2002.

[5] M.H. Carr, et al., Final report: southeastern ecological framework, May 2002, http://www.geoplan.ufl.edu/epa/download/sef_report.pdf.

[6] K.C. Clarke, L.J. Gaydos, Loose-coupling a cellular automation model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore, Geographical Information Science 12 (7) (1998) 699–714.

[7] K.C. Clarke, L. Gaydos, S. Hoppen, A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area, Environment and Planning 24 (1996) 247–261.

[8] Columbus Water Works: http://www.cwwga.org/cww/index.html.

[9] J. Craig, Military Base Leaders Gain Voice on Zoning Augusta Chronicle, June 4, 2003, p. B06.

[10] V.H. Dale, D. Druckenbrod, L. Baskaran, M. Aldridge, M. Berry, C. Garten, L. Olsen, R. Efroymson, R. Washington-Allen, Vehicle impacts on the environment at different spatial scales: observations in west central Georgia, USA, Journal of Terramechanics, in press.

[11] V.H. Dale, L. Olsen, T. Foster, Landscape patterns as indicators of ecological change at Fort Benning, Georgia, Landscape and Urban Planning, in review.

[12] J.V. Dennis, Species using red-cockaded woodpecker holes in northeastern South Carolina, Bird-Banding 42 (1971) 79–87.

[13] Department of the Army, Integrated Training Area Management How-to Draft Manual: http://www.army-itam.com/public/archive/publications/pdfs/HowTo.pdf.

[14] Department of Defense Directive 4700.4: http://www.dtic.mil/whs/directives/corres/pdf/d47004_012489/d47004p.pdf.

[15] Department of Defense and US Fish and Wildlife Service. Integrated Natural Resource Management Plans Fact Sheet: http://endangered.fws.gov/DOD/inrmp.pdf.

[16] Final Environmental Impact Statement for Digital Multi-Purpose Range Complex, Fort Benning, GA: http://www.benning.army.mil/emd/_program_mgt/legal/DEIS.pdf.

[17] J. Doresky, K. Morgan, L. Ragsdale, H. Townsend, Effects of military activity on reproductive success of red-cockaded woodpeckers, Journal of Field Ornithology 72 (2) (2001) 305–311.

[18] Economic Growth Analysis System Version 4.0 User's Guide: http://www.epa.gov/ttn/chief/emch/projection/egas40/index.html.

[19] R.A. Engel, Conservation Partnering Opportunities for Military Departments, Public Agencies, and Private Conservators Presentation for the Naval Facilities Engineering Command, April 9 2003 (http://www.dtic.mil/ndia/2003environ/engel.pdf).

[20] R.T. Forman, D. Sperling, J. Bissonette, A. Clevenger, C. Cutshall, V.H. Dale, L. Fahrig, R. France, C. Goldman, K. Heanue, J. Jones, F. Swanson, T. Turrentine, T. Winter, Road Ecology: Science and Solutions, Island Press, Washington, DC, 2002.

[21] J. Frankston, Mixed-use projects a hard sell in Atlanta Atlanta Journal-Constitution, October 13, 2003, p. 1F.

[22] C. Frost, Four centuries of changing landscape patterns in the longleaf pine ecosystem, Proceedings of Tall Timbers Fire Ecology Conference, vol. 18, 1993, pp. 17–44.

[23] Georgia Department of Industry, Trade, and Tourism: http://www.georgia.org.

[24] Georgia Community Greenspace Program: http://www.ganet.org/dnr/greenspace/index.html.

[25] Georgia Department of Transportation, Governor's Road Improvement Program (GRIP): http://www.dot.state.ga.us/DOT/plan-prog/planning/programs/grip.

[26] Georgia Department of Natural Resources, Environmental Protection Division: http://www.dnr.state.ga.us/dnr/environ.

[27] Gigalopolis Model Website: http://www.ncgia.ucsb.edu/projects/gig/index.html.

[28] F.S. Gilliam, W.J. Platt, Effects of long-term fire exclusion on tree species composition and stand structure in an old-growth *Pinus palustris* (longleaf pine) forest, Plant Ecology 140 (1999) 15–26.

[29] T.A. Greene, Management framework development and implementation of management goals and objectives associated with the Fort Benning Army Installation's Integrated Natural Resource Management Plan, Final Report, The Nature Conservancy, 2002.

[30] J.D. Haywood, A.E. Tiarks, M.L. Elliott-Smith, et al., Response of direct seeded Pinus palustris and herbaceous vegetation to fertilization, burning, and pine straw harvesting, Biomass & Bioenergy 14 (1998) 157–167.

[31] S. Kane, R. Keeton, Fort Benning: The Land and the People, Southeast Archeological Center, National Park Service, Tallahassee, FL, 1998.

[32] Longleaf Alliance: http://www.longleafalliance.org.

[33] L.K. Mann, P.D. Parr, L.R. Pounds, R.L. Graham, Protection of biota on nonpark public lands: Examples from the US Department of Energy Oak Ridge Reservation, Environmental Management 20 (1996) 207–218.

[34] D.H. McCay, Effects of chronic human activities on invasion of longleaf pine forests by sand pine, Ecosystems 3 (2000) 283–292.

[35] T. McCoy, J. Markham, Fort Benning ITAM program restores heavy mechanized training area Environmental Update, Spring 2002: http://aec.army.mil/usaec/publicaffairs/update/spr02/spr0211.html

[36] J. McMurray, Georgia City Aims to Turn Human Waste into Fertilizer, Chattanooga Times Free Press, January 4, 2004, p. NG3.

[37] Natural Resources Conservation Service, US Department of Agriculture: http://www.ga.nrcs.usda.gov/programs.

[38] R. Noss, Longleaf pine and wiregrass: keystone components of an endangered ecosystem, Natural Areas Journal 9 (1989) 211–213.

[39] Office of the Secretary of Defense, Base Realignment and Closure: http://www.defenselink.mil/brac.

[40] J.M. Omernik, Ecoregions of the conterminous United States, Annals of the Association of American Geographers 77 (1987) 118–125.

[41] J.M. Omernik, Ecoregions—a framework for environmental management, in: W. Davis, T. Simon (Eds.), Biological Assessment and Criteria, Lewis Publishers, Boca Raton, FL, 1995, pp. 49–62.

[42] W.J. Platt, G.W. Evans, S.L. Rathnun, The population dynamics of a long-lived conifer (*Pinus palustris*), American Naturalist 131 (1988) 491–525.

[43] W.J. Platt, G.W. Evans, M.M. Davis, Effects of fire season on flowering of forbs and shrubs in longleaf pine forests, Oecologia 76 (1988) 353–363.

[44] D. Pendered, East lake, greenway earn awards Atlanta Journal-Constitution, November 10, 2003, p. 1F.

[45] J. Pelley, Building smart-growth communities, Environmental Science and Technology 33 (1) (1999) A28–A32.

[46] C.W. Prosser, K.M. Skinner, K.K. Sedivec, Comparison of 2 techniques for monitoring vegetation on military lands, Journal of Range Management 56 (5) (2003) 446–454.

[47] H. Quicke, R. Meldahl, J. Kush, Basal area growth of individual trees: a model derived from a regional longleaf pine growth study, Forest Science 40 (1994) 528–542.

[48] C.G. Rizy, D.P. Vogt, P. Beasley, Economic characterization of RSim counties, ORNL Report, 2004.

[49] C. Seabrook, Water costs likely to rise; legal tangle: the US supreme court probably will be the next battlefield for the tri-state dispute, Atlanta Journal-Constitution, September 8, 2003, p. 1F.

[50] S. Shelton, Going for green space: the ground rules change, Atlanta Journal-Constitution, January 5, 2004, p. E1.

[51] Sikes Act, Digest of Federal Resource Laws of Interest to the US Fish and Wildlife Service: http://laws.fws.gov/lawsdigest/sikes.html.

[52] The Trust for Public Land: http://www.tpl.org/tier3_cdl.cfm?content_item_id=11351&folder_id=2306.

[53] The Trust for Public Land, Chattahoochee Riverway Project: http://www.tpl.org/tier3_cdl.cfm?content-i-tem_id=1135&folder_id=785.

[54] The Valley Partnership (located within the Greater Columbus Chamber of Commerce): http://208.62.83.218/ED/VP/Index.cfm.

[55] US Army, Army regulation 200-1 Environmental Protection and Enhancement, US Department of the Army, Washington, DC, 1997.

[56] US Census Bureau: http://www.census.gov/population/cen2000/phc-t3/tab05.pdf.

[57] US Environmental Protection Agency: http://www.epa.gov/owow/tmdl/intro.html.

[58] J. Walker, in: G.L. Miller (Ed.), The Value of Old Growth Forest Ecosystems of the Eastern United States: Conference Proceedings, 1993 August 26–28; Asheville, NC, University of North Carolina, Asheville, NC, 1999, pp. 33–40.

[59] H. Westbury, SEMP research and monitoring of the Fort Benning digital multipurpose range complex preferred site, Draft Report, March 2004.

[60] C. Williams, Group braces for Benning's defense, Columbus Ledger-Enquirer, January 22, 2004, p. B06.

[61] B. Woodson, Encroachment: Use of Army Compatible Use Buffers (ACUBs), www.hqda.army.mil/acsimweb/doc/IMI2004/IMI-encroachment-UseofACUBsv.II.ppt.

[62] C. Yoo, Alliance unveils its site plan for hill country, Atlanta Journal-Constitution, November 24, 2003, p. 2F.